Eyetracking correlated in the Matching Pairs Game

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***Abstract*—The video games industry has made available frameworks and methodologies that can support many applications in education, medical assessments, and rehabilitation programs. This study proposes a gamified approach based on Matching Pairs (MP) game to evaluate memory skills and performance in a cohort of 18 healthy subjects. An eye-tracking (ET) device was adopted to acquire the participants' gaze patterns while playing three consecutive instances of the card memory game. Eye gaze data has been analyzed to extract eye movements and velocity. Moreover, a statistical analysis was carried out to investigate possible differences in eye dynamics between trials, and a correlation analysis was performed between game statistics (i.e., total score, time, number of flipped cards) and ET-related parameters. Results showed that the maximum eye velocity differed between the first and second trials and eye movements (i.e., saccade and fixation count) and velocity significantly correlated with game duration and the number of flipped cards, respectively. These preliminary outcomes highlight possible relationships between eye dynamics and mental mechanisms for memory recall strategy. Furthermore, this study explored the feasibility of the proposed strategy to be applied to elderly or fragile people to contrast cognitive decline.**

***Index Terms*—Serious Games, Matching Pairs, Memory, Eye-Tracking, Signal Processing.**

I. Introduction

The increasing importance of technology in meeting people's needs has brought about significant changes in various aspects of individuals' lives [1]–[5]. One of the domains that has been greatly influenced is the entertainment industry, where technology has played a crucial role in delivering innovative and satisfying experiences [6]–[8]. In recent decades, the video game industry, where technological advances and entertainment needs converge, has experienced rapid growth, with a global audience of 2.69 billion people and revenues of $158 billion in 2020 [9]. In order to appeal to a wider audience, the game industry was expanded to a wide range of genres, resulting in a diverse range of games that appeal to different preferences [10], [11]. Besides these developments, video game studies have expanded their scope beyond entertainment and have entered critical areas of human life, including medicine [12], psychology [13], and education [14]. In this regard, the term "serious games" has evolved as an innovative approach that uses game methodologies and principles to tackle serious issues and provide educational interventions or behavioral changes. [15], [16]. As an impact of serious games, several studies have applied gamification strategies to the elderly with cognitive disorders such as dementia [17] or Alzheimer's disease [18] to enhance specific cognitive skills, as in particular memory.

Memory can be defined as the general name of the multi-stage process of keeping the acquired information in mind [19]. This multi-stage process is divided into encoding, storing, and retrieving information [20]. Encoding is the first step in converting incoming sensory stimuli into a format that can be registered and stored in the memory system. Storing is the process of maintaining this information over time for later retrieval. Retrieving is the process of recalling and accessing stored information from memory to make it accessible for current cognitive processing [20], [21]. Memory can be classified into 3 different types according to its duration: sensory memory, short-term memory, and long-term memory. Sensory memory is responsible for retaining information received from the senses for a very short period of time, typically less than a second. Short-term memory temporarily stores information for a short period of time before it is forgotten or transferred to long-term memory. Long-term memory allows information to be stored for a longer period of time, ranging from a few minutes to a lifetime [22], [23]. In considering these different memory types, video games have emerged as alternative and interactive tools that can assess and improve memory capacities in various scenarios. This study is focused on the development and evaluation of the Matching Pairs (MP) game, for assessing and improving short-term memory with one of the specific memory tasks. Generally, in this game, players are challenged to match symbols on cards with their

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identical pairs. The game involves up to 100 cards which are arranged in a face-down position, making it impossible to view the symbols on them. Players take turns selecting two cards and revealing them to the other players. If the symbols on the selected cards do not match, they are turned back over. The player who successfully matches a pair of cards removes them from the game screen [24], [25]. The game ends when all the matching pairs have been identified, and there are no more cards left. This game is specially designed to stimulate the memory capacities of players and to encourage their participation. It requires players to actively engage their visual and spatial memory, making it an effective way to improve memory skills [25]. Memory, which is actively used during the game, is known to be related to many Time-Varying Complex Cognitive Processes (TVCCPs) [26].

The evaluation and assessment of TVCCPs are challenging tasks that, according to the existing literature, often require the analysis of physiological signals such as electroencephalography (EEG). Several studies employed EEG as a straightforward neurofeedback technique in serious games and virtual reality experiences assessments for subjects with attention deficit hyperfunction disorder [27], [28], especially in the context of short-term and working memory. Eye tracking (ET) represents an alternative, non-invasive method that has been successfully applied in psychopathology [29], attention [30], computer science [31], imagination [32], and memory [33]. Recent works employing a combination between eye tracking and video games have highlighted that children had longer latencies and shorter fixation durations compared to adults [34]. Green and Bavelier's [35] study revealed that action game players can handle smaller target-distractor distances compared to non-players, providing evidence for a causal relationship between video game playing and increased spatial resolution. Research has also revealed that longer fixation duration is associated with higher mental effort and cognitive load [36], [37]. In addition, saccade reaction time has been linked to higher central nervous system function, and it has been demonstrated that saccadic eye movements during reading involve different patterns such as "jump and rest" [38], [39]. Furthermore, longer saccades indicate the occurrence of split attention effect [36]. Therefore, the study of eye patterns during game sessions can be a valuable variable that contributes to both the understanding of player performance and the assessment of their cognitive well-being. Considering this complexity, two hypotheses can be made:

- Does the performance of players and eye metrics change between multiple trials in a MP game?
- Do eye metrics reflect player performance in a MP game?

In this study, we report on an exploratory study focused on healthy subjects to assess the feasibility of a system based on an MP game and an ET device. The aim is to analyze players' strategies through ET-related metrics and investigate possible relationships between gaze dynamics and game performance. This approach might provide a first insight into mental mechanisms and enable further applications to the older population for well-being maintenance, to support rehabilitation treatments, and contrast cognitive decline.

II. Materials & Methods

The gaze signal was acquired using Tobii Pro® Glasses 3 (Tobii Pro AB, Danderyd, Sweden) with a sampling rate of 50 Hz. A triggering system based on optical sensors was used to monitor start and end time instants for the MP game.
Thirty-one healthy volunteers (13 females, mean age = 26.1 ± 2.8 years) were recruited in the study, however, thirteen subjects were removed due to various criteria (e.g., lack of synchronization, uncompleted trials). All participants gave written informed consent.

A. Matching Pairs Game

A customized version of the classic MP game was presented. This version consisted of 12 symbols, forming a total of 6 pairs. Figure 1 shows an example of both the flipped and not flipped versions of the symbols. Before starting the experiment, participants made one demo trial to familiarize themselves with the game and its mechanics. Demos results were not retained for data analysis. Each participant was given three trials for the game, with a maximum time limit of 35 seconds for each trial. The game was reset for each trial, and the symbols' positions were randomized. Each trial started by flipping the first symbol and enabling the countdown for the 35-second time limit. The trial concluded when the time ran out or the participant successfully identified all the symbol pairs. To calculate the participants' performance scores, each participant received an initial allocation of 100 points for each round. The final score was determined by deducting the completion time (X) and the number of symbols opened (Y) from the initial 100 points (100 - X - Y). If participants failed to finish the game within 35 seconds, they incurred a penalty of -10 points.

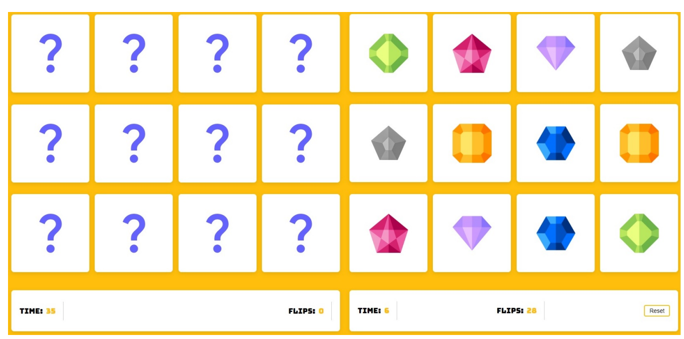

Fig. 1. Matching Pairs Game

B. Eye-tracking analysis

Each Gaze signal acquired from subjects underwent a preprocessing procedure:

1) The eye-tracking matrix was decomposed in its x- and y-coordinates, which are separately elaborated;
2) Artifacts, e.g., calibration losses due to sudden head movements and blinking, were detected and removed

considering upper and lower bounds. They were computed with the signals' median and the median absolute deviation (MAD). Specifically, the upper bound corresponded to $median + 5 * MAD$, whereas the lower bound was set at $median - 5 * MAD$.

3) A shape-preserving piecewise cubic interpolation was applied.
4) Outliers removal was performed with a moving average filter.
5) Finally, the eye-tracking matrix was recomposed with filtered x- and y- coordinates

Figure 2 summarises these preprocessing steps [40].

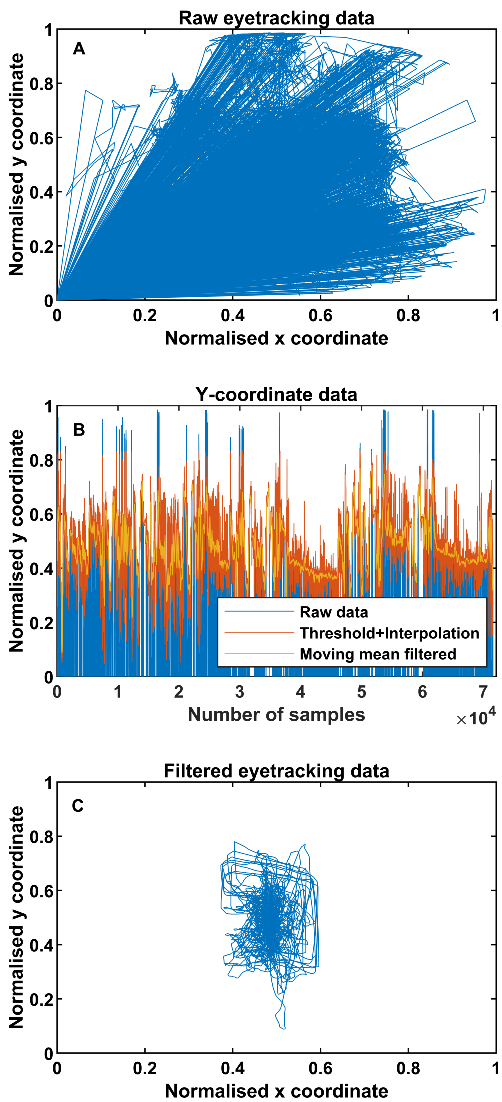

Fig. 2. Preprocessing steps. A) Raw gaze signal. B) Preprocessing procedure. C) Filtered raw signal.

Gaze velocity was computed according to the pseudocode proposed by Salvucci and Goldberg [41]. More into detail, point-to-point velocity was computed as the distance between two consecutive points in the filtered gaze 2D matrix. Equations 1 and 2 show how velocities in the x-and y-axis were separately computed before creating a mono-dimensional vector of gaze velocity.

$$v_x(n) = \frac{x_G(n+1) - x_G(n)}{\Delta t} \quad (1)$$

$$v_y(n) = \frac{y_G(n+1) - y_G(n)}{\Delta t} \quad (2)$$

The signal of the triggering system was then used to automatically segment data in three windows (corresponding to the three card games trials) where to perform feature extraction. In each interval, four statistical features were extracted: mean velocity, velocity standard deviation (STD), maximum (max), and minimum (min) velocity. Moreover, to account for the number of faster eye movements during trials, it was a computed metric that considered when gaze velocity goes beyond a threshold set at velocity $mean + 3 * STD$. Finally, following the threshold indication given in [41], saccades and fixations were detected, successive fixations were grouped, and then the other four parameters were calculated: the number of fixations and saccades and their respective mean duration.

C. Statistical analysis

The first hypothesis aimed at discovering possible significant differences in performance and ET-related measures between the three-game trials. Appropriate Statistical Analysis was performed following the data structure, the Friedman test, and repeated measures one-way ANOVA were considered to account for a paired data framework as the same participants played three consecutive game trials. Consequently, a post-hoc analysis was carried out either with paired samples t-test or Wilcoxon signed rank test with Bonferroni correction. The normality assumption was checked by performing a Shapiro-Wilk test. The $alpha$ level of significance was set at 0.05. The second hypothesis investigated possible relationships between physiological measures and game scores, game trial duration, and the number of flipped cards. Thus, Pearson or Spearman correlation analysis was performed following the results of the Shapiro-Wilk test. Moreover, for statistically significant differences between trials, the correlation was computed separately for each card game trial. Otherwise, all physiological metrics and scores were averaged between the three trials to perform a generalized correlation analysis.

III. Results

None of the parameters showed Normal distribution, therefore Friedman test and post-hoc Wilcoxon signed rank test for the first hypothesis and Spearman correlation analysis for the second hypothesis were performed.

A. First Hypothesis

Friedman test did not identify significant differences between trials except for maximum velocity ($p - value = 0.0242$). Post-hoc analysis highlighted a significant difference between the first and second trials ($p - value = 0.0156$). Figure 3 shows the boxplots for maximum velocity divided by trial, whereas Figure 4 displays boxplots for game score (panel A), game trial duration in seconds (panel B), and the number of flipped cards (panel C), divided by trial as well.

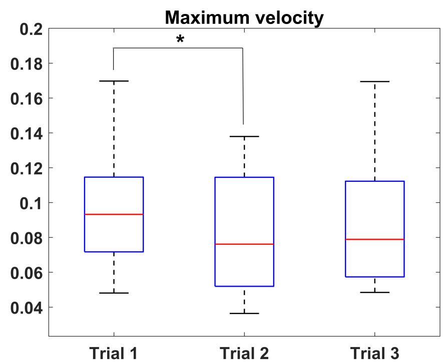

Fig. 3. Boxplots for eye movements maximum velocity. (*) denotes a statistically significant difference between Trial 1 and 2.

B. *Second Hypothesis*

The first hypothesis results highlighted that trial scores did not differ significantly. Therefore a generalized correlation analysis was carried out. No significant correlation was found when considering relationships between eye velocity features and MP game total score. In absolute value, the highest ρ coefficient was $\rho = -0.39$ for saccades mean duration, but its relative p-value was *p-value*$= 0.1147$. Significant correlations were identified considering the two variables from which the total score depends, i.e., trial duration and total number of flipped cards. Table I summarises correlation analysis results between physiological parameters, the total time taken to complete a trial, and the total number of flipped cards. Table I displays parameters that only present significant correlations, reporting correlation coefficient ρ and p-value. Table II displays median and interquartile ranges for the parameters that showed significant correlations, divided by trial.

TABLE I
CORRELATION ANALYSIS RESULTS BETWEEN EYE VELOCITY METRICS AND TRIAL DURATION [S] AND TOTAL NUMBER OF FLIPPED CARDS

	Trial duration	
Feature	ρ	p-value
Saccades count	0.56	0.016
Fixations count	0.55	0.017
	Number of flipped cards	
	ρ	p-value
Minimum velocity	-0.48	0.04

TABLE II
STATISTICS OF THE SIGNIFICANT CORRELATED PARAMETERS

	Trial 1	**Trial 2**	**Trial 3**
Feature	Median±iqr	Median±iqr	Median±iqr
Minimum velocity	$(8\pm6)*10^{-4}$	$(10\pm7)*10^{-4}$	$(9\pm9)*10^{-4}$
Saccades count	12±17	16±13	15±20
Fixations count	11±10	13±10	14±16

IV. DISCUSSION

This study proposed a first exploratory analysis of eye velocity and movements acquired during an MP game. Several studies have underlined a link between memory-based games and eye movements: e.g., in a back working memory game, Scharinger et al. [42] identified a significant difference in the total fixation duration between two levels of difficulty due to a stronger focus of participants in checking their performance score. Moreover, a similar metric, i.e., the total visit time during an information decoding phase, was significantly related to a logical memory score obtained while playing a short-term memory task [43].

In our study, participants played three instances of an MP game, and no significant difference was found in the game score. It is possible to observe from Figure 4 that performance was lower in the first trial compared with the second and third trials, but these shifts were not significant as its p-value was 0.26. The only parameter that the Friedman test highlighted as statistically significant was the overall maximum eye velocity, which was lower in the second trial than the first (Figure 3). It may mean that after a familiarization phase in the first trial, where the observed scene was scanned more rapidly by players, eye movements became steadier. Interestingly, when correlation analysis was performed separately for each trial, maximum velocity never significantly correlated with either game score, trial duration, or the total number of flipped cards.

Significant correlations were found between trial duration and eye movements: Table I highlights a positive relationship between trial duration and saccade occurrence and fixation. Both these metrics may have reflected a higher dwelling time on the observed scene and consequently cause tasks to last longer since players seem to explore them with greater depth in the game interface, possibly due to greater difficulty in finding matching pairs. This finding was also consistent with previous studies of eye movement patterns and cognitive processes [36], [37], [44], [45]. However, it is interesting to notice that both saccades and fixations occurrence were higher in Trial 2 and 3 than in Trial 1. In contrast, the boxplot for the total game duration is relevantly, but not significantly (p-value$=0.27$), lower in the last two trials. It may suggest a higher number of movements and fixations do not hinder game completion time and hence game performance.

Moreover, the averaged minimum eye velocity was negatively correlated with the number of flipped cards: it seemed then that when players flipped a major number of cards, e.g., in case of higher error rates in finding correct pairs, their minimum eye velocity decreased. It may appear contradictory, but this could mean that, as they attempted to find matching pairs before the 35s time limit expired, participants changed their strategy and scanned the game interface more slowly to increase their recall effort, underlying a possibly higher memory load. The wide distribution of the game score variance in the third trial could be attributed to cognitive fatigue (Figure 4A). This latter aspect should be further analyzed by implementing more repetitions of the MP game and including

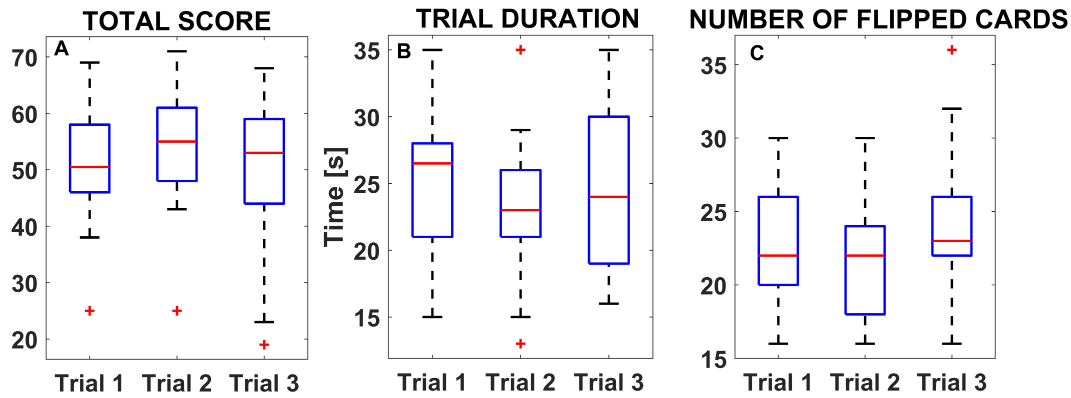

Fig. 4. Boxplots for game statistics. A) Game score. B) Game duration in seconds [s] C) Number of flipped cards within the trial.

analyses of psychological questionnaire scores. Furthermore, it should not be ignored that a process of understanding and establishing the game's underlying logic is developed during the player's first attempt. This condition could be an explanation for the lower performance of the first trial and higher game duration, where participants were not able to finish the trial within time limits (Figure 4A and Figure 4B).

In essence, the cards in the MP game were randomly distributed on the screen, and symbols positioned under the hidden cards were replaced at the beginning of each trial. Given the inherent randomness of the game itself, the player attempted to develop a performance strategy for each trial. This sense-making/heuristic strategy was influenced by in-game events and shaped according to the course of the game (e.g., matching the first two cards opened). It might have been that each trial had its characteristics, resulting in specific strategies and eye movements. Anyway, both Friedman test on game scores between trials and correlation analysis between them and eye velocity and movements did not identify any significant difference except for maximum eye velocity. It is possible that the procedure did not account for other factors (e.g., the number of successes or failures in a row). Therefore, involving more subjects and establishing adequate scoring will be important. In future research, brain and electrodermal activities could also be explored to study specific activation of memory-related cerebral areas and arousal level while playing MP games.

V. Conclusion

The first hypothesis of significant differences in-game performance and eye-related dynamics were not entirely met as only one parameter, i.e., the maximum eye velocity, was significantly lower in the second instance of the MP game rather than the first one. In future research, it will be important to understand whether these results will be confirmed with possible variations of the memory game considering, for example, the number and spatial arrangement of cards. This change might induce relevant adjustments in the visuo-spatial processing of subjects, thus allowing a better investigation of the underlying and implicit mnemonic processes.

The second hypothesis of correlation between memory processes and eye movements and velocity metrics during the overall course of the game proved that no correlation exists between the last set of features and game performance. Therefore it is necessary to introduce a novel scoring method that may account for the allowed number of errors, time limit, rewards, and penalizations. However, significant correlations were found between game duration and the occurrence of saccades and fixations and between the total number of flipped cards and minimum velocity. These results, though preliminary, highlight how eye-tracking can be successfully used to study memory game processes and strategies.

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